DEVELOPMENT AND IMPLEMENTATION OF JOINT PROGRAMS FOR LASER MEASUREMENTS

ANNUAL REPORT
April 29, 1996 through April 30 1997

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INTERNATIONAL PROGRAMS

WEGENER

During this reporting period as the NASA Special consultant to WEGENER, Dr. Pearlman continued to provide program coordination between NASA and the WEGENER Consortium. Pearlman provided technical, organizational, and functional support to the WEGENER Program and worked to facilitate group interaction among the WEGENER participants.

In 1995, a new WEGENER leadership was chosen with Professor Suzanna Zerbini as the new president, replacing Dr. Peter Wilson who had served since the inception of the program in the early 1980's. The new WEGENER Executive Board met at the University of Bologna on October 16-17 to review and update the WEGENER Mission and to form new working groups. It was agreed that the program should focus its activities a little more in concert with the interests of the European Scientific Union in order to be in a better position to seek funding support. The three main objectives as worded in the Expanded WEGENER Program in 1991 were preserved, but a more limited Program of Activities was adopted. The science objectives, program of activities, and committee memberships were included reference 1. Under the new reorganization, Prof. Suzanna Zerbini now chairs the Executive Committee, Dr. Hans Peter Plag (Kiel Institute of Geophysics, Germany) chairs the Science Advisory Committee, and Dr. Berndt Richter (IfAG, Germany) chairs the Technology Committee. Drs. David Smith and Mike Pearlman serve on the Science Advisory Committee, John Bosworth and Dr. John LaBrecque (position now vacant) serve on the Executive Committee, and Drs. John Degnan and Tom Clark serve on the Technology Committee.

The Seventh General Assembly of the WEGENER Project was held in Porto, Portugal on June 3-5, 1996. The list of participants and the agenda appears in reference 2. Introductory lectures on geodynamics and crustal deformation of the Mediterranean region, post glacial rebound, and height variation and sea level helped introduce the session topics. Forty papers were given on theoretical aspects and measurement results conducted with GPS, SLR, DORIS, etc., within

WEGENER. Most notable were the crustal motion models now being developed from the space measurement activities. Ten papers were also given on measurement techniques. A number of individual GPS measurement programs in the areas have now been informally included under the WEGENER umbrella.

The meeting of the new WEGENER Board was held in Porto on June 6 to (1) plan a proposal for the European Union, and (2) organize a Plenary Proceeding and (3) develop a plan for a WEGENER Science Position Paper. It was agreed that WEGENER should try to try for a single publication including a science position paper redefining program objectives, program justification and modus operandi, followed by a selection of papers from the Plenary meeting.
Pearlman prepared the trip report for the US delegation to the WEGENER Meetings (See Ref. 2).

The WEGENER Report has been prepared and assembled under the guidance of Hans Peter Plag and Suzanna Zerbini and submitted for publication in a special issue of Tectonophysics. It is now in review. Many of the project participants contributed.

At the moment all three of the transportable laser ranging systems, TLRS-1, MLRS-1, and MLRS-2 are in residence at Matera, Wettzell, and Kootwijk respectively, awaiting resolution of funding and programmatic issues. No occupations were conducted during the past year, but efforts are underway so see how these resources could be used to strengthen the project in the future.

Preparations are underway for the Eighth General Assembly of WEGENER and a WEGENER Board Meeting during June 9 - 11, 1997 at Maratea, Italy. We are also trying to organize a working group to develop some coordinated programs in the Middle East Region.

The WEGENER Project is doing well. The new leadership has considerable depth and is well organized. Membership and interest continues to grow. The scientific scope as evidenced by the scientific papers presented at the General Assembly reflect the growth.

Asian Pacific Space Geodynamics (APSG) Program

Pearlman participated in the Asian-Pacific Space Geodynamics (APSG) Program Meeting held in Shanghai on May 13 - 17. Sixty participants from Australia, China, Germany, Hong Kong, Indonesia, Korea, New Zealand, Pakistan, Philippines, Russia, and the USA attended. Forty papers were given on the dynamics and deformation of the Asian and Western Pacific Regions, techniques to conduct measurements, and current programs already underway that could provide synergy. See reference 3 for the list of attendees and the program agenda. Using material drafted by the APSG President, Prof. Shu-Hua Ye, Pearlman and Peter Wilson drafted the APSG Program Document which they presented to the attendees for discussion in the final sessions of the meeting. The program objectives as developed at the meeting are:

1. To measure and monitor, using space techniques, the relative deformations at and around the plate tectonic boundaries;

2. To study the evolution of the crustal motions for the tectonic island-arc system in the Western Pacific boundary zone and the mountain-building zones of the Tibetan Plateau and SE-Asia and their dynamic mechanism;

3. To measure and monitor sea-level change in the Asia-Pacific area, to study the characteristics and causes of the fluctuations of the global ocean surface as well as the mechanisms leading to its variation;

4. To investigate the variation of the spatial motion of the Earth as a whole and the mass motion of each layer of the Earth and the associated dynamic relations;

5. To investigate the occurrence and regulation of disasters as well as their relation to various Earth motions, and to provide basic information for the prediction of disasters.

There appeared to be strong interest both inside and outside China for an APSG program and tentative plans are afoot to organize a second meeting in Hawaii next year, but followup in organizing the program activities seems to be very slow. They need some help.

INTERNATIONAL SLR NETWORK SUPPORT

Helwan Observatory

Under this contract, the Helwan SLR Observatory was to be operated for a period of three months annually in support of NASA Programs. The station was originally set up as a joint US-Egyptian-Czech Program using funds provided by the Smithsonian Institution. Once the station was fully operational, NASA began providing funds for three months of operation each year to support NASA and international programs. Due to budgetary uncertainty, NASA was not able to fund the Helwan operation this past year. However, the Helwan Institute for Astronomy and Geophysics (Egypt) and the Technical University of Prague were able to do some system work to improve performance in the expectation of future NASA support. A NASA GPS receiver has been setup at Helwan.

Bar Giyyora

An new agreement between NASA and Israel has finally been completion under which NASA will provide a permanent GPS receiver as a geodetic reference station to support both global and regional programs. However, due to the political situation in the area, the Bar Giyyora station has been reclaimed by the police for border security and a new site, preferably at one of the Universities in Israel, is being sought for the GPS receiver, . The IPRG and Avi Shapira are no longer involved with the project; the Israeli Space Agency has chosen Shimon Wdowinski of the

Tel Aviv University as the Technical Contact. We know him; he is a very good choice.

We need to get this site issue resolved; this situation needs some stoking.

SALRO

Pearlman has been a member of the SALRO Acceptance Board since its inception six years ago. In 1995, the system was given guarded approval for shipment based on the results of its collocation tests at GSFC.

Pearlman participated in the pre-acceptance data review for the Saudi Arabian Laser Ranging Observatory (SALRO) held in July 12. With Degnan, Varghese, and Fischetti, he travelled to Riyadh, Saudi Arabia on July 18 - 24 to participate in the Final Acceptance Test Review Board on the SALRO. The system which was built by Electro Optic Systems of Australia performed well, and the Board recommended acceptance. An assessment on operational, infrastructure, and personnel issues was also provided. While in Riyadh, Pearlman participated in the writing of the Board Report (reference 4) which was presented and submitted to the Vice President for Research Institutes, King Abdulaziz City for Science and Technology, in Riyadh. We also had the opportunity to work with the station crew and become more familiar with the laser ranging system. Pearlman wrote the trip report for the US delegation (reference 5).

Discussions have been underway with Dr. Mohammed Al-Dail of KASCT on a program to use GPS and SLR to measure the opening of the Red Sea. Discussions have included colleagues from MIT, Scripps, Lamont-Doherty Earth Observatory, and HSTX, with an eye toward submitting a proposal to NASA next year. While in China in November, Pearlman also met with Dr. Attieh Al-ghamdi from Saudi Arabia and Dr. Maher Tawadros from Helwan Institute for Astronomy and Geophysics (HIAG) to discuss further the program to use GPS and SLR to measure the opening of the Red Sea.

San Fernando

Pearlman and Degnan visited the Observatorio de Marina SLR site in San Fernando, Spain on May 31 to meet the staff, to review system configuration and performance, and to encourage them toward more contact with other SLR groups and with international organizations such as the SLR Subcommission of the CSTG. The ranging system, originally furnished by the French, has been almost entirely rebuilt by the Observatorio. We were very impressed with the equipment and the staff. With a little technical help, this group could be a strong participant in the global network. Details on the visit and recommendation for technical improvement of the stations are included in reference 2.

Former Soviet Union Stations

SAO and the Crimean Astrophysical Observatory have been awarded a grant from the United

States Civilian Research and Development Foundation to upgrade the Simiez SLR station. The grant includes $52 K over two years for equipment, local salaries, and travel. However, funding for the project has been held up because of a general taxation dispute between the government of the Ukraine and outside funding agencies regarding taxation.

Chinese Stations

The Chinese SLR network with SLR stations in Shanghai, Beijing, Changchun, and Wuhan have contributed some data to the global network, but data has been sparse and of irregular quality. All of the stations have been visited at least once during the last several years, and NASA has provided some funding for the purchase of needed components through the University of Texas to help improve performance.

While in China in May, Bosworth, Ma, and Pearlman met with representatives of the Chinese Academy of Sciences to discuss cooperative programs in SLR and VLBI, and in particular how the Chinese network could be improved. Followup activity is underway to see how NASA and other overseas groups might be more effective in helping the Chinese SLR stations improve performance. Attendees of the APSG Meeting also visited the SLR and VLBI facilities at the Shanghai station.

In November Degnan, Shelus, and Pearlman visited the Yunnan Observatory in Kunming where they are currently installing SLR capability. The excellent location, the large telescope, and the dedicated staff lead us to believe that with proper support this could be the best SLR operation in China. See reference 6 for the status of the SLR implementation. Upon our return from China, Pearlman worked with C.K. Shum/CSR, Ben-Chun Wang/U Md., and John Degnan to develop a budget request for continued NASA support for the Chinese SLR Network. (reference 7). In response, NASA has allocated $54 K for this fiscal year. A decision has been made to provide key subsystems to the Kunming station, provided sufficient progress has been made since our visit last November. Pearlman and Shum are in contact with the station now to assess the current status.

We will need to allocate some engineering talent to work with Kunming to develop work plans, to monitor progress, and to help them formulate operational procedures.

INTERNATIONAL COORDINATION

CSTG

Dr. Pearlman is one of the three U.S. representatives on the Steering Committee of the SLR Subcommission of the CSTG. In 1992, he was chosen as the Subcommission Recorder. He works with John Degnan, the Steering Committee Chair to organize and run the meetings, document the proceedings and issue a meeting reports, including the assignment of action items and delineation of key issues. He takes a major role in the assembly of the CSTG newsletter and in the

formulation of policies and positions to be discussed by the Subcommission.

Pearlman participated in the SLR/LLR Subcommission Meetings of the CSTG in June in Porto and in Shanghai in November. As Recorder for the SLR Subcommission, he wrote the Subcommission Meeting notes. (reference 8 and 9.) A number of operational and data issues were addressed, but the major item was the start of a reorganization to try to make the international laser tracking network more effective and more responsive to user needs. Action is now underway to have a proposal for reorganization ready for review by the membership at the next Subcommission meeting at Maratea just after the WEGENER Meeting. The notes from the meetings in Porto and Shanghai have also been placed on the CDDIS WWW page by Carey Noll.

Pearlman worked with John Degnan and Carey Noll to assemble articles for the Laser Ranging Newsletter for the SLR/LLR Subcommission. He organized a survey of the SLR data analysis groups on data usage and needs, and he helped to organize a Historical Summary of SLR Technology, Programs, and Scientific Accomplishments for programmatic use.

RELOCATION OF NASA SLR SYSTEMS

TLRS-1 in Italy

TLRS-1 was transferred to ASI/Italy for support of the WEGENER program. Plans for upgrading and subsequent deployment to the field had to be shelved due to funding constraints at ASI. The TLRS-1 is in storage at Matera awaiting a decision on disposition.

MOBLAS-8 to Tahiti

Pearlman continues as a consultant on the relocation of the MOBLAS-8 laser to Papeete, Tahiti in French Polynesia. The agreement has been signed and construction of the SLR facility at the French University of the Pacific is underway. A French technician is in the US undergoing training. Shipment and setup at the site is scheduled for the July-August timeframe.

MOBLAS-6 to South Africa

Pearlman continued as a consultant on the relocation of the MOBLAS-6 laser to South Africa. Three options are being considered: (1) Sutherland (Astronomical Observatory), (2) Hartebeesthoek (VLBI Observatory), and (3) Stellenbosch (University). The collaboration with GFZ to locate an SLR as a part of a new geodetic observatory at Sutherland has apparently disappeared, but options 2 and 3 remain very much active. Most interesting at the moment is an offer from Dr. Garth Milne, from the University of Stellenbosch offering to host and operate a MOBLAS system at the University. Both options (2) and (3) are being pursued now and a trip to South Africa later in the year to meet with the Foundation for Research and Development (FRD) and the other key players to work out the best situation will probably be necessary.

NASA SLR System to India

Preliminary discussions are underway between Tom Varghese/ATSC and the Indian Space Research Organization (ISRO) regarding a relocation of a NASA SLR system to India in a partnership arrangement. NASA awaits a visit from Dr S. Rangarajan, Director of the ISRO Telemetry Tracking and Command Network to discuss details. A trip to India will be necessary to work out the operational issues.

TECHNICAL AND OPERATIONAL SUPPORT

Engineering Support

Pearlman continued to provide technical and operational support and overview for NASA in the field of laser ranging including: system performance evaluation, system diagnosis, and system engineering, and provided technical support to ATSC engineering and software staffs. David Carter is now running the SLR bi-weekly telephone conferences and writing the meeting reports.

Data Engineering Panel

Pearlman chaired the SLR Data Engineering Panel. The panel met on May 1 to discuss: (1) an apparent range bias between the LAGEOS satellites and TOPEX/Poseidon, (2) performance of the Chinese SLR stations, and (3) recent changes in SLR format and data corrections. Pearlman prepared notes from the meeting. (reference 10). The panel met on August 8 to discuss:(1) station range bias discrepancies between Lageos and Topex, (2) closure on the SALRO FAT, (3) data format corrections, and (4) content and format for an SLR Performance Session at the Laser Workshop in Shanghai. (reference 11). Performance of some of the network stations was also reviewed. Subsequent meetings were held in September and October to plan the Workshop session. The session is intended to address ways of improving SLR overall network and individual station performance and how we can be more responsive to our customers' needs.

Due to scheduling conflicts, the SLR Data Engineering Panel did not meet during the third quarter, but several operational data issues were resolved by Van Husson, Andrew Sinclair, and the SLR Subcommission Working Group on Data Format Issues. An SLR Data Engineering meeting was held on February 26 to discuss treatment of retroreflector array anomalies and performance of European and NASA stations.

Technical Workshops and Meeting

Pearlman participated in the Tenth International Workshop on Laser Ranging held in Shanghai, PRC on November 11-15, 1996. Pearlman chaired the first day session on Station Performance Evaluation and submitted a paper on Laser Ranging Performance Evaluation (reference 12) for inclusion in the Proceedings.

While in China in November, Degnan and Pearlman met with representatives of the Russian Space Agency for discussions on cooperation on new SLR satellites and the upgrade of Russian ground stations. Pearlman also attended the Western Pacific Laser Tracking Network Plenary Session.

SLR REVIEW COMMITTEE

In response to budgetary limitations, NASA convened an SLR Review Committee, chaired by Irwin Shapiro, to assess the future of SLR and to scope a program of reduced cost. Pearlman, as Executive Secretary of the SLR Review Committee, made the preparations for meetings, facilitated the correspondence among Committee members and NASA, developed the cost models, and worked with Irwin Shapiro and the Committee Members to write the final report and prepare the presentation which was given to Bill Townsend and Bob Price on April 3. The Executive Summary with the Committees recommendations is included as Appendix 1.

The response to the report was very favorable and hopefully it will set the tone for some long range stability in the SLR program. After some further clarification of some issues within the science section of the text, the final version of the report was submitted in late April. (reference 13).

KEY CONTACTS

The scientific and technical contacts made and renewed during the tenure of this contract are listed in each trip and meeting report tabulated in the Bibliography.

REPORTS

Details on the above activities are included in trip report, technical reports, and quarterly reports submitted to NASA during the tenure of this contract.

REFERENCES

1. Report on Trip to (1) Wettzell, Germany on October 12-13 to participate in the EUROLAS SLR Technology Workshop and (2) Bologna, Italy on October 16-17 to participate in the WEGENER Board Meeting, November 21, 1995.

2 Trip Report to (1) San Fernando, Spain to Visit the SLR Station at the Observatorio de Marina, and (2) Porto, Portugal to participate in the Seventh General Assembly of the WEGENER Project, the SLR Subcommission Meeting of the CSTG. and the LAGEOS II Science Working Group Meeting, May 28 - June 7.

3. Trip Report - (1) First Workshop of the Asia-Pacific Space Geodynamics (APSG) Program and (2) Meeting on the Status of the Chinese SLR and VLBI Stations; Shanghai, China; Dates: May 10 - 19, 1996.

4. Report of the Saudi Arabian Laser Ranging Observatory, Final Acceptance Test (FAT) Review Board, July 20 - 23, 1996

5. Trip Report - Final Acceptance Test (FAT) of the Saudi Arabian Laser Ranging Observatory (SALRO) in Riyadh, Saudi Arabia, July 18 -24, 1996.

6. Trip Report to Shanghai, PRC to participate in the Tenth Workshop on Laser Ranging Instrumentation, and to Kunming, PRC to visit the SLR station at the Yunnan Observatory, November 8 - 24, 1996; dated December 26, 1996.

7. Support Plan for the Chinese SLR Station, prepared for submission to NASA; dated December 15, 1996

8. Report on the SLR Subcommission of the CSTG Meeting in Porto, Portugal, June 6, 1996.

9. Notes from the Plenary Session and the Steering Committee Session of the CSTG held on November 12 and 15, 1996 in Shanghai, PRC; dated January 15, 1997.

10. Report on Data Engineering Panel Meeting of May 1, 1996.

11. Report on Data Engineering Panel Meeting, August 8, 1996.

12. Laser Ranging Performance Evaluation, submitted for inclusion in the Proceedings of the the Tenth International Workshop on Laser Ranging held in Shanghai, PRC on November 11-15, 1996.

13. SLR Review Committee Report, April 1997

SLR REVIEW COMMITTEE REPORT

Executive Summary

Mandate

The Satellite Laser Ranging (SLR) Review Committee was formed by Miriam Baltuck, Chief of the Solid Earth and Natural Hazards Branch at NASA Headquarters, to

1. make a recommendation as to whether or not the NASA SLR activity should continue, and why; given a positive recommendation, then

2. review a GSFC plan for future NASA SLR activities;

3. advise NASA on whether a productive SLR program could be conducted by the Mission to Planet Earth Program Office at an annual funding level of $3.8 M, and if not, what minimum level would be required; and

4. present its findings in a report.

In response to that mandate (see Appendix I), the Committee report is presented below.

Committee View of the SLR Program

The Committee agreed that:

1. in terms of science and applications, SLR:

   a can make significant additional scientific contributions to NASA programs in Earth physics, ocean physics, lunar science, and relativity;

   b. will continue to be a major source of precision tracking for a number of spaceborne applications and an important backup for other tracking techniques; and

   c. in combination with radio techniques will likely provide a useful synergy for understanding error sources and thereby improving the accuracy of determining orbits and site positions;

2. precipitous withdrawal or severe reduction in the NASA SLR support for the twenty-one retroreflector satellites now in orbit and the six additional satellites to be launched over the next twelve months will present NASA as a very unreliable partner in future space activities;

3. the proper global role for SLR today is to provide a fiducial network of at least a dozen high performance stations (normal point ranging standard errors under 1 cm and data from over 1500 passes per station per year) that are geographically well distributed in both latitude and longitude (this view confirms the conclusions in the Proceedings of the 1989 Coolfont Conference and the 1991 National Research Council Study: International Global Network of Fiducial Reference Stations);

4. NASA should continue to play a strong role in this global SLR network, as detailed in our recommendations below (note, too, that SLR was initiated and nurtured by NASA and that NASA-operated systems still rank highest in data quality and quantity); and

5. Whatever the funding level, NASA should commit within its legal constraints to not lowering that level for at least a five-year period to allow the program to proceed efficiently.

SLR Team Plan

The SLR Team presented a plan based on:

1. modest reduction of the present network;

2. modest reduction in infrastructure; and

2. development and fielding of an automated SLR 2000 system at eight sites in the FY 2001 timeframe.

The annual cost given in this plan ranges from $6 - $7 M, until SLR 2000 is implemented in FY 2001(see Table 3).

In evaluating this plan, the Committee noted the following issues:

1. Networks

   a. at more than $200 K (i.e., 40%) higher than the annual cost of operations at any other station, the cost of the Maui (HOLLAS) SLR station seems quite high (see Table 2 for SLR system definitions);

   b. with the plan's proposed closing of the McDonald (MLRS) SLR station:

      i. SLR would lose a strong technology group and an important contributor to the organization of an international program; and

      ii. the US participation in lunar laser ranging would cease.

2. Infrastructure

The annual infrastructure support for the network ($2.6 M) seems to the Committee to be higher than absolutely necessary. Although the Committee is not in a position to reorganize network activities and then fully assess the impact, the Committee suspects that further reductions are possible without devastating effects.

The Committee is also concerned that the Team's plan does not include sharing the cost of infrastructure functions with other non-US SLR groups either through distributing functions among several groups or having several groups contribute people to work at one site on all of these functions.

3. New Systems

The development of a new, fully automated system makes good sense since there are compelling reasons for NASA to continue its SLR program well into the next century. However, the Committee is concerned that:

a. other options for cost sharing the development and implementation of a new SLR system, which would be a global standard, have not been fully explored; and

b. cost and schedule for development and implementation of the new system may be optimistic.

Program Options

Based on:

1. the budget details provided by the SLR Team; and
2. the observations and concerns listed above,

we estimated the cost for a suite of program options for comparison with the $3.8M guideline and considered the impact of each on both the science and applications areas. We present only two of these options, our recommended option and one that comes closest to meeting the guidelines in our mandate. Our recommended option is based on the assumption that NASA will develop SLR 2000 alone. If any of our other suggestions (above) on the development of a new system and the sharing of infrastructure costs bear fruit, the budget for this option would change accordingly. The option covers seven years beyond FY 1997, which is the period that we assumed would be required to develop and implement the SLR 2000, or equivalent, based on our assumptions above. We also present the option that comes closest to meeting the $3.8 M annual budget guideline. We do not, however, recommend this option.

Before we present these two options, we make several additional observations:

1. Because of transition and closeout costs, the FY 1997 expenses will be no less than nearly $7 M for all "reasonable" options;

2. A sensible scope of NASA network operations and a fully NASA-sponsored development of an SLR 2000-type system cannot both be accommodated simultaneously within a budget even close to $3.8 M per year; and

3. Even an austere, but perhaps not unreasonable, plan for network operations alone has an annual budget that exceeds $3.8 M.

Option 1

Given:

1. the important contributions to science that SLR could make in the future; and
2. the importance of SLR tracking to satellite orbit determinations,

the Committee recommends the following option (Option 1):

1. NASA funded stations at:

   a. GSFC(MOBLAS-7),
   b. McDonald (MLRS),
   c. Maui (HOLLAS) or less expensive equivalent, and
   d. Arequipa (TLRS-3).

2. Yarragadee taken over by the Australians at the beginning of FY 1998; in the meantime NASA would pay the operations costs (if the cost of operation of the Yarragadee station were not then taken over by the Australians, it would be closed);

3. MOBLAS systems transferred to:

   a. Tahiti, and
   b. South Africa;

4. TLRS-4 or equivalent system transferred to India;

5. infrastructure reduced to 18 people; and

6. SLR 2000, or equivalent, development and implementation program undertaken on about a $1.25 M per year level-of-effort budget.

The estimated annual budget for Option 1 decreases from about $7.6 M in FY 1997, to $6.1 M in FY 1998, $5.8 M in 1999, and $5.6 M thereafter until the SLR 2000 or equivalent is implemented (see Schedule 1 for a summary of the costs and Schedule 1(d) for the budget details).

The cost of this option exceeds the budget guideline given to the Committee. However, in the Committee's opinion, it is about the minimum budget that would allow NASA both to continue operations at a reasonable fraction of the stations that compose the global SLR network and to develop and field a next generation SLR system. The cost of this option might be reduced through participation by non-US partners in the development and replication of such new systems and through cost sharing of infrastructure.

Option 2

The Committee also considered an option (Option 2) that would allow operations of SLR systems to continue, but would exclude expenditure of further funds on new systems. Under this option, the same stations would be supported as under Option 1, except that the GSFC station would be closed. The annual cost of Option 2 decreases from $6.6 M in FY 1997, to $4.4 M in FY 1998, $4.0 M in FY 1999, and about $3.9 M thereafter (see Schedule 2 for a summary of the costs and Schedule 2(d) for the budget details). Even this quite austere option fails to meet the budget guideline and is very likely to lead in future years to substantial cost increases for operations and maintenance. The Committee does not recommend this option; it is a dead end for SLR.

Committee Recommendations

A summary of the Committee's recommendations follows:

1. NASA should continue its role in SLR within the context of a global network of at least a dozen sites with NASA working with its non-US partners to:

    a. achieve the best feasible geographic distribution of tracking stations;
    b. improve existing stations in key geographic locations to reach high performance;
    c. share operations experience and technology development;
    d. continue SLR operations and data analysis (e.g., system maintenance, data processing, quality control, data analysis and scientific interpretation - see 4., below); and
    e. continue development of new SLR technology to improve performance and cost effectiveness (see 6.,below);

2. within this network, NASA should:

    a. continue to support those of its present stations that provide coverage of geographically important areas not covered by others (see list above under Option 1);

b. seek ways to reduce the cost of the SLR operation in Hawaii, examining other locations if necessary;

c. transfer the Yarragadee station to the Australians at the beginning of FY 1998 (if the operation of the Yarragadee station were not then taken over by the Australians, it would be closed);

d. transfer the MOBLAS-8 and MOBLAS-6 SLR systems to Tahiti and South Africa, respectively;

e. transfer the TLRS-4 or equivalent system to India;

f. operate these stations with maximum temporal coverage, except for Arequipa which should continue operating on its present two-shift basis;

g. complete the improvements now in process to increase automation; and

h. through equipment loan, infrastructure support, and technical advice, continue its current policy of helping network partners to set up, maintain, and improve stations, but only in geographically key regions;

3. NASA with its international partners should direct strong efforts toward:

   a. reducing the biases in the SLR data to well below the centimeter level; and
   b. validating and refining the troposphere refraction model so that it is essentially unbiased and the residual errors are mainly random from pass to pass;

4. NASA should seek ways to share cost of infrastructure functions (e.g., system maintenance, data processing, quality control, data analysis and scientific interpretation) with other non-US SLR groups through either:

   a. distributing functions among several groups (e.g., through the SLR Subcommission of the IAG/IUGG/COSPAR-sponsored International Coordination of Space Techniques for Geodesy and Geophysics); or

   b. having several groups contribute people to work at one site on all of these functions (CERN model);

5. NASA should develop a 5-7 year maintenance plan based on experience to date to:

   a. assess the realism of present cost assumptions; and
   b. produce an "optimum" strategy for preventive maintenance;

6. in regard to SLR 2000:

    a. NASA should make a survey of:

        i. other SLR systems under development that might lend themselves in whole or in part to this application; and

        ii. industry for possible participation in the development and construction of future systems;

    b. NASA should make a strong effort to organize the SLR community toward global standardization of future systems and participation by both US and non-US partners in the development of a low cost, fully automated SLR capability;

    c. NASA should insure that in any such development a prototype stage is included to demonstrate system utility and realism of cost and schedule for system production, installation, and operation; and

    d. if the efforts under b., above, fail to yield useful results and NASA "goes it alone", then NASA should proceed on a level-of-effort basis (about $1.25 M per year) to:

        i. reduce the annual funding requirement; and

        ii. give proper time for well thought-out options and proper prototype development and testing;

7. if at all feasible, NASA should select budget Option 1 (Option 2 is a dead end for SLR); and

8. whatever the funding option chosen, NASA should within its legal constraints commit to not lowering that level for at least a five-year period to:

    a. allow the NASA program to proceed efficiently, and
    b. make reliable commitments to our international partners whose own SLR programs are intimately connected with NASA's.

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